NISTIR 5604

LEAST - COST ENERGY DECISIONS FOR BUILDINGS - PART III

Choosing Economic Evaluation Methods

Video Training Workbook

Prepared by
HAROLD E. MARSHALL

Office of Applied Economics
Building and Fire Research Laboratory
For
The Federal Energy Management Program
U.S. Department of Energy

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U.S. DEPARTMENT OF COMMERCE
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Preface

This workbook accompanies the video training film "Choosing Economic Evaluation Methods: Least Cost Energy Decisions for Buildings." It is the third in a series of training videos designed to assist you in using economic analysis to improve the long-run economy of your buildings. This module describes the types of investment decisions that you will have to deal with when you evaluate energy conservation projects—decisions like whether to accept or reject a project, what size or design alternative to choose, and what priority to assign candidate projects. And then it tells you how to match different types of decision problems with appropriate economic methods. As the primary training tool, the video can be used alone. However, it is recommended that it be used in conjunction with this workbook, which provides the following:

* *expanded descriptions of technical material in the video*

* *figures and tables presented in the video*

* *formulas for computing economic measures used in the video*

* *exercises to give you practice*

* *glossary of technical terms used by the instructors*

The order of presentation in the workbook follows that of the video to simplify using them together. But the workbook provides more detail on the economic methods than does the video. A glossary of technical terms is in Appendix A. Professional profiles for the two instructors that appear in the video are given in Appendix B.

The running time for the video is 35 minutes. Pause the video as needed in the technical passages to refer to the workbook.

For references to other works on choosing economic evaluation methods, see Appendix C. For an expanded treatment of how to make least-cost energy decisions for buildings, take one of the two-day Life-Cycle Cost Workshops offered either by the National Institute of Standards and Technology or by Department of Energy qualified trainers at locations throughout the U.S. See Appendix D for the address, telephone number, FAX number, and E-mail address for information about up-coming workshops and how to order publications referenced in the video and workbook.

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1. Finding the Right Methods

The theme of the video is how to find the right economic methods to evaluate building investment decisions. The first instructional video[1] in this series provides fundamental tools for discounting cash flows, computing life-cycle costs, and evaluating energy conservation projects. The second video[2] helps you establish a reasonably complete economic picture of project alternatives when you are faced with uncertain information. This third video provides the analyst the needed skills for choosing the most appropriate economic evaluation methods. Finding the right method is important, because using inappropriate methods of economic evaluation can lead to decisions that result in economic losses.

The roadmap analogy in the video supports the "find-the-right-method" theme by showing how searching for the right method is similar to finding your way along a map to a specific destination. The routes on the map represent the economic methods. The destination on the map represents the specific type of building decision you face. Figure 1-1 illustrates the map analogy. It directs you to the appropriate economic methods that will help you make major investment decisions regarding the design, sizing, acceptance, and ranking of projects. To use the map, first you find your destination—i.e., the type of decision, as represented by one of the building labels on the map. Examples are Design decisions, shown at the upper left of the map, and Accept or Reject decisions, shown at the lower left. Then travel up and down "Economic Evaluation Boulevard" in the center of the figure until you find the exit for the route (i.e., method) that takes you to the type of decision you need to make.

Try using the map to see if you can find the right methods for some specific decisions. To determine the priority or ranking of projects competing for a limited budget, as shown on the right side of the map, you could choose either the Adjusted Internal Rate of Return—AIRR route on the map—or Savings-to-Investment Ratio—the SIR route on the map. To determine whether to accept or reject a project, as shown at the bottom left, you could use any of the methods. That is, each of the methods has a road that leads to the accept or reject destination.

While the map serves well as a guide among the various methods, it fails to guide you to the *best* route from among those roads on the map that lead to your destination. More information is needed before you can make that choice.

This video and workbook package identifies the types of building investment decisions (i.e., destinations on the map) you might encounter; reviews five frequently-used economic methods that you can use in making those decisions; recommends methods for specific investment decisions;

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[1]See Ruegg, Rosalie T., "Introduction to Life-Cycle Costing," Part I in the Audiovisual Series on Least-Cost Energy Decisions for Buildings, April 1990. VHS tape and companion workbook are available from Video Transfer Inc., 5709-B Arundel Avenue, Rockville, MD 20852. Telephone (301) 881-0270.

[2]See Marshall, Harold E., "Uncertainty and Risk," Part II in the Audiovisual Series on Least-Cost Energy Decisions for Buildings, April 1993. VHS tape and companion workbook are available from Video Transfer Inc., 5709-B Arundel Avenue, Rockville, MD 20852. Telephone (301) 881-0270.

demonstrates the economic losses that arise from making decisions based on an inappropriate method; provides tips on selecting the best method; and presents problem exercises in classifying the type of decision and choosing the right method.

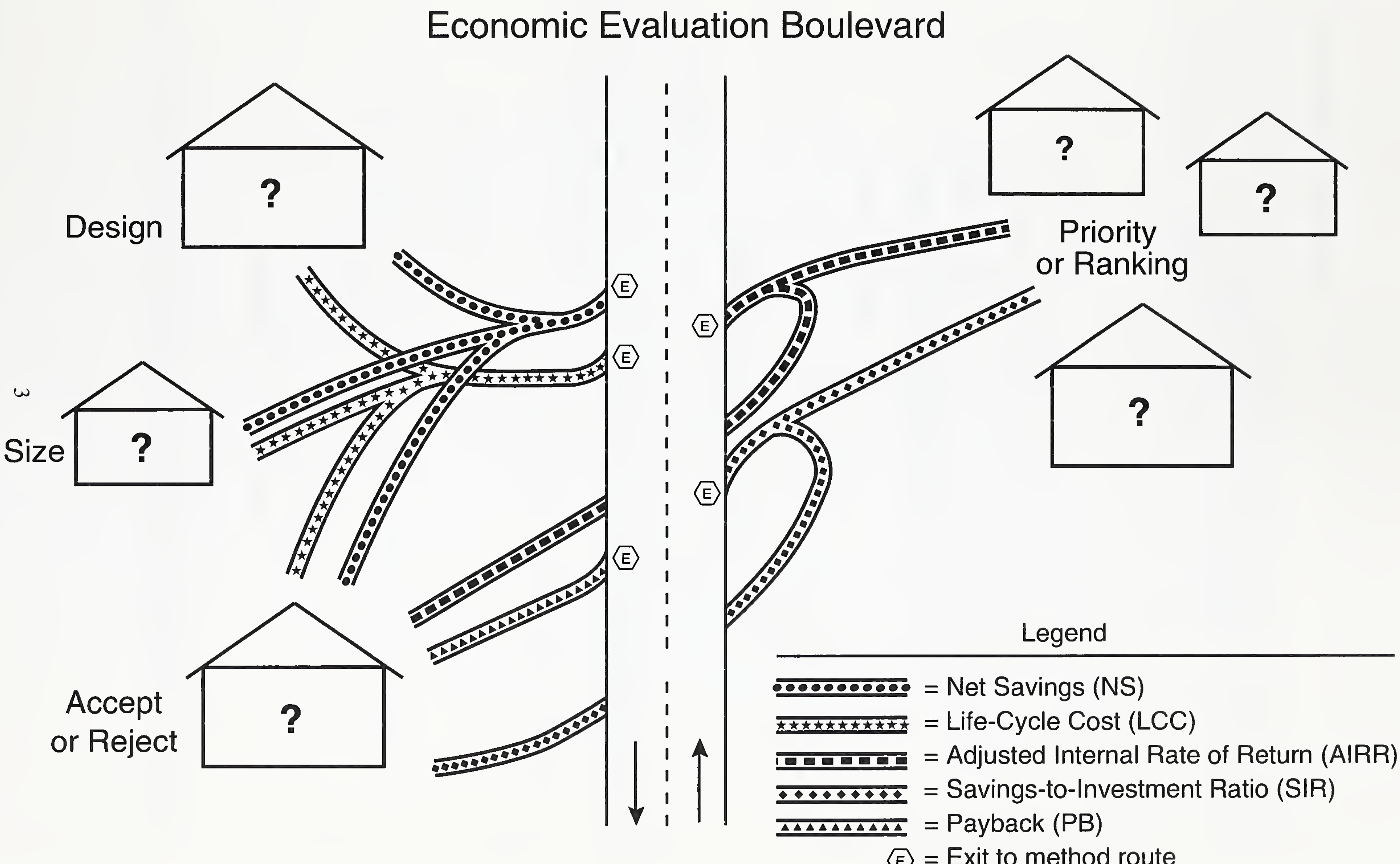

Figure 1-1. Methods map.

2. Investment Decisions

The first step in finding the right economic methods is to identify what type of investment decision you want to make. Exhibit 2-1 shows the five principal types of investment decisions that you are likely to encounter in an energy conservation project. Each will be defined in turn and illustrated with some typical building examples.

Accept/Reject
Efficiency Level or Size
System or Design
Combination of Interdependent Projects
Priority or Ranking

Exhibit 2-1. Investment decisions.

2.1 Accept/Reject

An accept/reject decision refers to deciding on whether or not to go with a project when you are considering a single design or system option. Exhibit 2-2 lists some typical building investments that might require an accept/reject decision.

* Storm Windows
* Solar Heating System
* Water Heater Insulation Kit

Exhibit 2-2. Accept/reject.

Adding storm windows is a typical investment to reduce energy consumption. Will the reduced energy bills return enough present value savings to pay for purchase and installation? Will adding

a solar heating system pay for itself? And will installing a water heater insulation kit be cost effective?

Note that the emphasis in the video is on the measurable economic impacts of these investments—that is, benefits and costs that can be quantified in monetary terms. But be sure to consider other impacts of the investments. For example, if the installation of storm windows makes the house less drafty and therefore more comfortable, that is a side benefit that you will also want to consider in making your accept/reject decision.

2.2 Efficiency Level or Size

Exhibit 2-3 lists three typical building values about which you have a choice. The best economic choice for level of thermal resistance for wall insulation, for example, is that level at which life-cycle costs of insulation and energy consumption are minimized. You need an economic method such as LCC to evaluate those alternative resistance levels to see which is economically best. Likewise, the collector area for a solar energy system and the seasonal efficiency rating for an air conditioner are parameters that can be evaluated on the basis of their economics.

* Wall Insulation R-Value
* Collector Area for Solar System
* Seasonal Efficiency Rating for Air Conditioner

Exhibit 2-3. Efficiency level or size.

2.3 System or Design

You have a system or design decision when you try to choose the most cost-effective of multiple alternatives, all of which meet your minimum performance requirements. Exhibit 2-4 lists typical building elements and materials about which system or design decisions must be made for most buildings.

* Oil, Gas, or Electric Heating

* Insulation Materials

* Wall System

Exhibit 2-4. System or design.

Do you choose oil, gas, or electric heating when all are available at your site? For your insulation material, do you choose fiberglass, foam, or cellulose? And for your wall system, do you choose a glass curtain wall or a masonry wall? Selecting the right economic method helps steer you to the cost-effective choice.

2.4 Combination of Interdependent Projects

Some projects are *inter*dependent, in that changing the level of investment in one project will have an impact on the economic value of other projects. For such projects you need to consider interdependencies within the group when you make project choices. Exhibit 2-5 lists two projects that are interdependent. If you add more insulation to your attic, for example, it will affect the cost effectiveness of upgrading your heating system. While it may be economical to add insulation, it may not pay to *then* upgrade your heating system—even though a heating system upgrade would be cost effective with the original level of insulation. Interdependent projects must therefore be evaluated in combination rather than separately.

* Insulation R-Value

* Level of Heating System Efficiency

Exhibit 2-5. Interdependent projects.

2.5 Priority or Ranking

You can also have a group of cost-effective projects that are independent. That is, choosing any one has no economic impact on the others. Making choices among those projects becomes a priority or ranking decision when there is insufficient funding to do all the projects in the group. Suppose you are a facilities manager with a complex of four buildings—A, B, C, and D. Suppose further that you have enough money for conservation investments in some of the buildings, but not all. Assume that your four cost-effective options, as determined by a prior economic analysis, are those shown in Exhibit 2-6.

* Energy Conserving Lighting Fixtures in A
* High-Efficiency Heating System in B
* More Attic Insulation in C
* Replacement Windows in D

Exhibit 2-6. Priority or ranking.

You need an economic method that will help you decide the order in which to choose these options as you spend down your limited budget.

Exhibit 2-7 lists examples of typical building decisions, classified according to four of the five general types described earlier. (No example is given of combining interdependent projects, as discussed in section 2.4. Note too that, while the exhibit and its source document do not include "system" with design and "level of efficiency" with size under the type-of-building-decision categories, examples of system and level-of-efficiency decisions are provided as part of the design and size categories.)

If you have trouble identifying the types of investment decisions that you face on the job, use Exhibit 2-7 to find examples similar to yours so that you can classify the types of decisions. That will be the first step in finding the right methods.

Type of Building Decision	Examples
Accept/Reject	Is a water heater insulation kit cost effective? Are fire sprinklers cost effective? Is a given control system cost effective for managing HVAC equipment? Is a solar hot water system cost effective?
Design	Is single, double, or triple glazing most cost effective? What heating system is most cost effective? Which orientation of a building is most cost effective? Which code-approved plumbing system is most cost effective? Which wall type (for example, masonry, wood frame curtain wall) is most cost effective? What floor finish (for example, carpeting, tile, wood) is most cost effective? What kind of insulation (for example, cellulose, fiberglass, rigid foam) is most cost effective? Is an item with low first costs more cost effective than a more durable substitute with higher first costs?
Size	What is the economically efficient level (R value) of insulation in the walls and above the ceiling of a house? How many square feet of collector area should be installed in a solar energy system? What heat pump efficiency (for example, HSPF 1.75, 2.0, 2.25) is most cost effective? What furnace efficiency (for example, AFUE 60%, 75%, 90%) is most cost effective? What air conditioner efficiency (for example, SEER 7.0, 9.0, 11.0) is most cost effective?
Priority or ranking	What combination of independent investments in a given building (for example, new water heater, new floor tile, and new lighting system) is economically preferred when each is justifiable on economic grounds, but insufficient funds are available to pay for all of them?

Exhibit 2-7. Examples of building investment decisions.

Source: E 1185-93 "Standard Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems," American Society for Testing and Materials, Table 2, Philadelphia, PA, 1993.

3. Economic Methods

In the roadmap analogy depicted in Figure 1-1, you saw that there are a number of routes, or economic methods, that help you make the different building investment decisions. Learning how to compute and interpret the economic measures associated with each method will help you choose the appropriate method for your investment decision. This section examines in some detail the economic methods for project evaluation listed in Exhibit 3-1.[3]

Life-Cycle Cost (LCC)
Net Savings (NS)
Savings-to-Investment Ratio (SIR)
Adjusted Internal Rate of Return (AIRR)
Payback (PB)

Exhibit 3-1. Economic methods.

These five methods are often used in making energy conservation decisions in buildings. You can make most decisions with the first three: life-cycle cost, net savings, or savings-to-investment ratio.[4] But there are circumstances when you will want to use one of the others. Each of the methods is reviewed so that you will have a complete selection to choose from. The formula, an example application to a building decision, and requirements for proper use are given for each method.

For help in computing the measures, you will want to use BLCC, the Building Life-Cycle Cost Computer Program, described in the box of Exhibit 3-2.

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[3]For an indepth treatment of these methods, see Ruegg, Rosalie T. and Marshall, Harold E., *Building Economics: Theory and Practice* (New York, New York: Chapman and Hall, August 1990), pp. 16-106, and Fuller, Sieglinde K. and Petersen, Stephen R., *Life-Cycle Costing Manual for the Federal Energy Management Program*, National Institute of Standards and Technology, Handbook 135 (Rev. 1995).

[4]Note that net benefits (NB) and benefit-to-cost ratio (BCR) methods are not discussed here. They are similar to the NS and SIR methods, except that they are used where projects yield benefits rather than cost savings. Since energy conservation projects yield cost savings almost exclusively, the focus here is on the measurement of savings. For an extensive treatment of BCR and NB, see Ruegg and Marshall, *Building Economics: Theory and Practice*, pp. 34-66.

BLCC

The Building Life-Cycle Cost (BLCC) computer program was developed at NIST for the economic analysis of buildings and building systems. It is designed to run on IBM PCs and compatibles. BLCC can compute the LCC for project alternatives and compare those LCCs to determine the most economic project alternative. It can compute the net savings, SIR, and payback period for any alternative relative to a base case. It can also generate an annual cash flow report for each alternative and print out detailed or summary LCC analysis. For a brochure with information on the BLCC program, contact the Office of Applied Economics at NIST (301) 975-6132.

Exhibit 3-2. Building life-cycle cost (BLCC) computer program.

3.1 Life-Cycle Costs (LCC)

The life-cycle cost, or LCC, of a project, as shown in eq 3.1, is the sum of initial investment costs; replacement costs; energy costs; operation, maintenance and repair costs—minus residual or salvage value, where all amounts are in present values. That is, the dollar amounts are adjusted for the time value of money.[5] LCC is the project's total cost over its period of analysis (often called study period). When alternative projects provide equal benefits, the project with the lowest life-cycle cost is the economical choice.

$$LCC = I_0 + Repl + E + OM\&R - Res \tag{3.1}$$

where I_0 = initial investment costs,
Repl = replacement costs,
E = energy costs,
OM&R = operation, maintenance, and repair costs, and
Res = residual or salvage value.

An alternative formula for computing the present value of LCC is shown in eq 3.2, where the discounting operations are explicit and all costs are lumped together in each time period.

[5]If you need help in understanding how to adjust cash flows to achieve time equivalent values, see the video and workbook on *Introduction to Life-Cycle Costing*, Part I in a series on Least-Cost Energy Decisions for Buildings, National Institute of Standards and Technology, 1990.

$$LCC = \sum_{t=0}^{N} \frac{C_t}{(1 + d)^t} \tag{3.2}$$

where C_t = Sum of all relevant costs, less any positive cash flows such as salvage, occurring in time period t,

N = number of time periods in the study period, and

d = investor's discount rate for adjusting cash flows to present value.

An example of an application of the LCC method is deciding which system design is best. Assume that you are specifying the heating and cooling system for a building. One alternative is the typical system for your area—an oil furnace with an electric air conditioner. It has a reasonable first cost and moderate operating expenses. Call this the base case. Another alternative is a heat pump with electrical resistance backup, with a higher first cost, but lower operating expenses. Assuming the two systems meet your target comfort levels for the building, choose the one with the lower LCC.

Here are some tips to keep in mind when using the LCC method. When using LCC analysis in finding the most efficient building solution among alternatives, you need to compute the LCC of each alternative. Typically you will compare the LCCs of your proposed design alternative(s) against the LCC of a base case alternative, usually the alternative with the lowest first cost.

While you can compare an unlimited number of alternatives in LCC analysis, an explicit assumption is that all of the alternatives that you consider for a project be capable of satisfying minimum performance requirements for the project (e.g., safety, reliability, and occupant comfort). Furthermore, LCC analysis is most suitable when project alternatives yield differences in cost savings rather than in benefits. If there are benefit differences, they must be netted from costs for the LCC analysis to be valid.

Finally, LCCs, when expressed in present value terms, must always be computed with the same discount rate and over the same study period (i.e., time over which you evaluate the alternatives).

3.2 Net Savings (NS)

Net Savings, or NS, as shown in eq 3.3, is the difference between life-cycle costs without the energy conservation feature under consideration and life-cycle costs with the energy conservation feature. If life-cycle costs are lower with the feature than without it, net savings are positive, and the conservation feature is economical.

$$NS = LCCw/o - LCCw \tag{3.3}$$

where LCCw/o = LCC without the energy conservation feature, and

LCCw = LCC with the energy conservation feature.

Taking the example cited earlier of choosing between the oil system and heat pump, you subtract the heat pump alternative's LCC from the LCC of the oil system base case and select the heat pump if NS are positive.

Note one major difference between using LCC and NS methods. An LCC analysis requires you to compare the LCC of each alternative to make a project selection, whereas NS analysis expresses the relative economic worth of two mutually exclusive projects in a single number.

3.3 Savings-to-Investment Ratio (SIR)

The savings-to-investment ratio, or SIR, is a numerical ratio whose size indicates the economic performance of an investment over the study period. Equation 3.4 shows that the SIR is the sum of a project's cost savings and other benefits divided by the investment amount on which you wish to maximize your return. To be cost effective, a project must have an SIR greater than one.

$$SIR = S/I \tag{3.4}$$

where S = cost savings plus any other monetary benefits, and
I = investment costs.

Equation 3.5 is an alternative formulation that shows mathematically the discounting of savings and investment streams and their summation into an SIR value.

$$SIR_{A:BC} = \frac{\sum_{t=1}^{N} S_t \,/(1+d)^t}{\sum_{t=0}^{N} \Delta I_t \,/(1+d)^t} \tag{3.5}$$

where $SIR_{A:BC}$ = The ratio of PV savings to additional PV investment costs of the alternative (A) relative to the base case (BC),
S_t = savings in operating-related costs, plus any benefits, attributed to the alternative in year t, and
ΔI_t = additional investment-related costs attributable to the alternative in year t.

To apply the SIR in choosing between the oil furnace base case and the heat pump alternative of our example, compare, in present value terms, the energy savings per extra investment dollars spent for the heat pump over the conventional oil furnace system. If the SIR exceeds 1.0, the heat pump is the economical choice. If it is less than 1.0, go with the oil system.

Remember that, like the NS measure, the SIR measure incorporates in a single number a comparison of two mutually exclusive project alternatives over the study period. Also, be aware that the

placement of cost items between the numerator and denominator within eqs. 3.4 and 3.5 can affect your ranking of investment alternatives when you are ranking independent projects with the SIR. So be sure to put only those investment costs in the denominator on which you seek to maximize your return.

3.4 Adjusted Internal Rate of Return (AIRR)

The adjusted internal rate of return, AIRR, measures the annual percentage yield from a project. It is superior to the unadjusted internal rate of return (IRR) because the AIRR can account for returns on reinvestment of project earnings at rates different from the rate earned on the original investment. For this reason, the AIRR is generally preferred to the IRR. To be economically acceptable, a project must have an AIRR at least equal to the investor's minimum acceptable rate of return (MARR).

Equation 3.6 is one formula for computing the AIRR. It is convenient to use whenever you have calculated the SIR. Other formulas exist,[6] but they can be quite complicated. You can use the BLCC computer program (described in Exhibit 3-2) to compute the AIRR.

$$AIRR = -1 + (1 + r)\,(SIR)^{1/N} \tag{3.6}$$

where r = rate at which earnings or savings can be reinvested.

3.5 Simple and Discounted Payback (SP & DPB)

The payback period is the minimum time that it takes to recover the costs of an investment. If, for example, it takes two years for the cumulative energy savings of a conservation project to cover investment costs, then payback is two years.

The minimum solution value of y in eq 3.7 is simple payback (SP).[7] It ignores the time value of money (i.e., there is no discounting in the formula). The equation requires an integer solution. (That is why an inequality appears in the equation.) You can determine a non-integer solution, however, through interpolation, if the data are available for time periods shorter than one year.

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[6]See Ruegg and Marshall, *Building Economics: Theory and Practice*, pp. 81-82, and Marshall, Harold E., *Recommended Practice for Measuring Net Benefits and Internal Rates of Return for Investments in Buildings and Building Systems*, National Institute of Standards and Technology, Interagency Report 83-2657, October 1983, pp. 24-30.

[7]For a description of various approaches to computing SP, see Marshall, Harold E., *Recommended Practice for Measuring Simple and Discounted Payback for Investments in Buildings and Building Systems*, National Institute of Standards and Technology, Interagency Report 84-2850, March 1984, pp. 10-14.

$$\sum_{t=1}^{y} (B_t - \bar{C}_t) \geq \Delta I_o \tag{3.7}$$

where B_t = additional benefits attributed to the alternative in period t,

$\bar{C}_t$ = additional costs attributed to the alternative in period t, and

ΔI_o = increase in initial investment costs attributed to the alternative.

Discounted payback (DPB) is a more accurate measure of payback because the time value of money is taken into account. DPB can be computed easily with the BLCC computer program,[8] and it provides a better indication of a project's cost effectiveness than does simple payback.

Payback has some attractive features. It is easy to understand. It shows you how long it takes for a project to break even. For example, in our heat pump versus oil furnace problem, you can figure how long it will take for the heat pump to pay for itself by computing its payback. Furthermore, as a supplementary method, payback is sometimes helpful in screening potential projects quickly. But both versions of payback give a poor measure of a project's profitability over the long run because they ignore cash flows after payback. The SPB will not even give you a reliable measure of the time to break even since it ignores the time value of money. So use LCC, NS, and the SIR routes in Figure 1-1 instead of payback if you want to be sure you are making the best economic decisions.

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[8]To learn how to compute DPB without a computer, see Marshall, Harold E., "A Graphical Approach to Discounted Payback," *Journal of Construction Management and Economics*, Vol. 3, No. 2, 1985, pp. 105-120.

4. Recommended Methods by Type of Decision

To do an economic evaluation, you must be able to identify the type of investment decision that you want to evaluate—that is, you have to identify your destination on the roadmap in Figure 1-1. Section 2 provides a classification of different types of investment decisions that will help you determine your destination. You must also understand the economic methods that are available—that is, the routes in Figure 1-1—and how to compute their measures of project worth. Section 3 describes those methods. Given that background, you are ready to learn how to select the appropriate method for your investment evaluation. Section 4 presents basic guidelines for matching investment decisions with the appropriate methods and points out common pitfalls to avoid.

Exhibit 4-1 from the video shows recommended methods for typical investment decisions. It provides some of the same information as the roadmap in Figure 1-1, but in a matrix format. Consult Exhibit 4-1 whenever you need a refresher as to which methods are best for you.

Type of Decision	LCC	NS	SIR	AIRR	DPB
Accept/Reject	Y	Y	Y	Y	Y*
Efficiency Level or Size	Y	Y	N	N	N
System or Design	Y	Y	N	N	N
Combination (Interdependent)	Y	Y	N	N	N
Priority or Ranking	N	N	Y	Y	N

Exhibit 4-1. Recommended methods.

The first column lists the types of investment decisions described in Section 2. The headings across the top of the chart are the five economic methods described in Section 3. (Only discounted payback is considered due to the limitations of simple payback.) The Ys, Ns, and Y* in the chart indicate whether or not that method is recommended for each of the decisions. Y means that the method is recommended, N means it is not, and Y* means it is recommended with limitations.

Note that for all decisions there are at least two methods from which to choose. While any one of those methods provides economic answers that support the same decision, there are likely to be special considerations that will make you prefer some methods over others. For example, you can use most of the methods in Exhibit 4-1 to choose whether to accept or reject a project. But the best method for you might depend on the culture of your organization. That is, if a ratio such as the SIR

is preferred over a percent-of-return figure in your institution, then your culture dictates that the SIR will be preferred over the AIRR.

Exhibit 4-2 (page 19) will help you sort through special considerations. It lists three types of special considerations that you need to be aware of before you select your method. They are the unit measure of cost effectiveness, nature of cash flows, and limitations associated with each method. Be sure to consult Exhibit 4-2 before making your final method selection.

The video breaks down Exhibit 4-1 by type of decision into separate exhibits. It then focuses in turn on each type of decision, identifying one or more economic methods that are appropriate, and providing rules for interpreting the economic measures computed under each method. The workbook follows the same approach.

4.1 Accept/Reject

Let us start with the decision on whether to accept or reject a project, as illustrated in Exhibit 4-3.

Type of Decision	LCC	NS	SIR	AIRR	DPB
Accept/Reject	Y	Y	Y	Y	Y*
Accept When	Min.	>0	>1.0	>MARR	<project life

Exhibit 4-3. Accept/Reject.

Take the LCC measure first. You must confirm that the alternatives to be compared all meet performance requirements and differ mainly in terms of their costs. If these special conditions are not met, choose another method. Then you calculate the life-cycle costs for leaving the building as it is. Compare these costs against the life-cycle costs of the proposed alternatives. Accept the alternative with the minimum (Min.) LCC.

For the net savings method, the simplest way to compute NS is to subtract the life-cycle costs with the project alternative from the life-cycle costs without it. Accept the alternative if net savings are greater than zero.

The SIR tells how many times greater a project's savings are than its costs. You need an SIR greater than one for an alternative to be acceptable on economic grounds.

The AIRR is the annual rate of return on your project investment. The AIRR must be greater than your minimum acceptable rate of return, or MARR, for the project to be economically sound.

Discounted Payback, DPB, must be a shorter period of time than the project life for the project to be acceptable. DPB is an unreliable method if negative cash flows occur after payback.

Method	Unit Measure of Cost Effectiveness	Nature of Cash Flows	Limitations
LCC	$	primarily costs	A single LCC measure gives no indication of economic merit of a building or building component. LCC values for two or more alternatives are required for an LCC comparison. Alternatives being compared must be equivalent in other respects than LCC and must be compared over the same study period.
SIR	dimensionless number	savings and costs	Alternatives must be compared over the same study period unless replacement assets can be expected to repeat the costs and savings of the original assets.
IRR and AIRR	percent rate of return	savings and costs	If the assumed rate of return on the reinvested earnings (savings) is not equal to the discount rate, then the IRR may yield inconsistent results with the BCR or SIR when ranking projects. Alternatives must be compared over the same study period unless replacement assets can be expected to repeat the costs and savings (benefits) of the original assets. The Unadjusted Internal Rate of Return method may give incorrect solutions and in some cases no unique solution.
NS	$	savings and costs	Alternatives must be compared over the same study period.
PB	time (usually years)	savings and costs	Cash flows beyond the payback period are ignored. The simple payback measure ignores the time value of money. Projects selected according to this criterion may not be cost effective.

Exhibit 4-2. Special considerations.

Source: This Exhibit is based in part on Table 3, Special Considerations, in the ASTM Standards on Building Economics Compilation "E 1185-93—Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems."

4.2 Efficiency Level/Size and System/Design

To find the most efficient level or cost-effective project size, system, or design, use either the LCC or NS methods, as shown in Exhibit 4-4. The rule is to select the level, size, system, or design with the lowest (or minimum) LCC, or the greatest (or maximum) NS.

Choosing the alternative with the highest SIR or AIRR, or with the shortest DPB, will *not* generally lead to the most economic alternative. If you compute the SIR and AIRR incrementally, on the other hand, you can use them to make size and design decisions.[9] Using the incremental approach increases your chances of making an error, however, so it is not recommended.

Type of Decision	LCC	NS	SIR	AIRR	DPB
Efficiency Level or Size	Y	Y	N	N	N
System or Design	Y	Y	N	N	N
Rule for Selection	Min.	Max.	--	--	--

Exhibit 4-4. Size or design.

4.3 Combination of Interdependent Projects

When you are trying to choose the optimal combination of interdependent projects, use either the LCC or NS method, as shown in Exhibit 4-5. Be sure to compute LCC and net savings for *combinations* of projects instead of single projects taken one at a time. With LCC, you want to find the combination of projects which minimizes the sum of life-cycle costs for all of the candidate combinations. With NS, select the combination that maximizes the sum of net savings for all the candidate combinations.

[9]For a detailed description of how to compute, display, and interpret incremental SIRs in choosing the appropriate level of investment, see Marshall, Harold E. and Ruegg, Rosalie T., *Recommended Practice for Measuring Benefit/Cost and Savings-to-Investment Ratios for Buildings and Building Systems*, National Institute of Standards and Technology, Interagency Report 81-2397, November 1981, pp. 21-29.

Type of Decision	LCC	NS	SIR	AIRR	DPB
Combination of Interdependent Projects	Y	Y	N	N	N
Rule for Optimal Combination	Min. Sum	Max. Sum	--	--	--

Exhibit 4-5. Combination of interdependent projects.

Your goal is to choose the right mix of sizes and designs for a group of interdependent projects. The HVAC system, thermal envelope, and lighting system in a building are all interdependent with respect to energy performance. Finding the optimal combination of investments among them as a group requires the use of the LCC or NS methods as shown in Exhibit 4-5.

4.4 Priority or Ranking

The last decision, how to establish priority or ranking of independent projects when your capital investment budget cannot fund them all, is shown in Exhibit 4-6.

Type of Decision	LCC	NS	SIR	AIRR	DPB
Priority or Ranking	N	N	Y	Y	N
Rule for Ranking	--	--	Descending Order	Descending Order	--
Rule for Selecting	--	--	Budget is Exhausted	Budget is Exhausted	--

Exhibit 4-6. Priority and ranking.

Suppose you have a group of independent projects, each of which is cost effective in the sense that it generates present value savings greater than its costs. Or, said differently, for each project the SIR is greater than one or the AIRR is greater than the minimum acceptable rate of return. Suppose further that your budget will not allow you to choose all of the projects. To get the maximum

benefits or savings from your choices, rank the projects in descending order of their SIRs or AIRRs.[10] Then select projects in descending order until the budget is exhausted. This selection procedure will help you maximize aggregate NS for your limited budget.

Where lumpiness in project costs results in some budget leftovers, neither the SIR nor the AIRR always guides you to the set of projects that maximizes aggregate NS if you simply select down the priority list. To maximize NS, you sometimes have to skip over higher-ranked projects with relatively high investment costs to select lower-ranked projects with relatively low investment costs. Remember, as long as the SIR exceeds 1.0 or the AIRR exceeds your MARR for a project farther down the priority list, it may pay to jump over a higher-ranked project. By putting more of the budget to work, you can increase aggregate NS. So whenever the budget is not completely used up when selecting projects by priority ranking, test alternative sets of projects using aggregate NS to see which set yields the greatest gains for the limited budget.[11]

LCC, NS, and DPB, when used to rank independent projects, will generally lead to an uneconomic set of project selections for the limited budget.

4.5 Summary of Methods

Keep in mind that LCC and NS methods will handle most of your economic evaluations. As Exhibit 4-1 shows, you need the SIR or AIRR methods only when you have to rank independent projects, or when you need to express results as a ratio or a percent.

Also weigh in your choice of method(s) any special considerations (Exhibit 4-2) or circumstances. If you do a Federal analysis, for example, you need to use the methods prescribed in the regulations.

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[10]Be sure to delete any project whose SIR is less than one, or whose AIRR is less than the minimum acceptable rate of return before starting the ranking process.

[11]For more information on how to deal with lumpiness, see Marshall, Harold E., "Economic Methods and Risk Analysis Techniques for Evaluating Building Investments—A Survey," *CIB Report Publication 136*, February 1991, pp. 24-25, and Ruegg and Marshall, *Building Economics: Theory and Practice*, pp. 61-64 and pp. 88-89.

5. Economic Losses from Using Inappropriate Methods

The need for selecting the right economic methods is best illustrated by showing the potential economic losses from decisions made on the basis of inappropriate methods.

5.1 Level of Attic Insulation

Consider a decision on the economic level of attic insulation for a residence. Our rule in Exhibit 4-4 tells us to select the level at which LCC is minimized or NS is maximized. Start by computing life-cycle costs for each level being considered for installation. Now, for comparison purposes, compute SIRs for each level. The roadmap (Figure 1-1) shows that the SIR is not the right route for this kind of decision. But let us see just how much that wrong turn might cost us.

5.1.1 R Value Chosen with LCC Method

Assume that you have a twelve hundred square foot house with an electric heat pump located in Ohio. Table 5-1 shows life-cycle costs over a 30-year study period for the combined present value costs of energy and insulation. Life-cycle costs are shown for no insulation and for five increasing levels, as measured by the insulation resistance (R) value from R=0 to R=49.

Table 5-1. Economically efficient level with LCC

R Values	LCC
R-0	$13,881
R-11	11,077
R-19	10,649
R-30	10,486
R-38	10,490
R-49	10,581

The minimum life-cycle cost is $10,486, at a resistance value of R-30. Life-cycle costs are lower at R-30 than at any other resistance level. You lose potential net savings if you install more, or less, insulation than R-30.

5.1.2 R Value Chosen with SIR Method

Now look in Table 5-2 to find the level of insulation that you would install if you used the SIR as the economic method.[12]

[12]This assumes that you do not calculate the SIRs incrementally.

Table 5-2. Comparison of levels with LCC and SIR

R Values	LCC	SIR
R-0	$13,881	0.0
R-11	11,077	10.3
R-19	10,649	8.2
R-30	10,486	6.2
R-38	10,490	5.2
R-49	10,581	4.3

The highest SIR is at R-11, the very first increment of insulation. You would expect that, because incremental energy savings tend to be more substantial for initial levels than for high levels of insulation.

5.1.3 Economic Loss From Using the Wrong Method

If you install R-11, as indicated by the maximum SIR value, look at what you lose—the difference between $11,077, the life-cycle costs that you incur at R-11, and $10,486, the lower costs you would incur at a level of R-30. The difference, a present value of $591, is the extra cost (or loss) you incur by choosing the wrong method.

5.2 Ranking of Energy Conservation Projects

Now let us look at a case where you need to rank projects because the budget is limited. You have four energy-conserving projects to evaluate. They are totally independent of one another. First try the SIR, which is an appropriate method. Then try net savings for individual projects, which is an inappropriate method. Then let us calculate the loss you will incur if you use the wrong method.

5.2.1 Ranking with SIR Method

The SIRs in Table 5-3 are greater than one for all of the projects, so all are cost effective. But their combined investment costs are $30,000, and you have a fixed budget of only $20,000. The rules for selection from Exhibit 4-6 are to take the projects in descending order of their SIRs until the budget is exhausted. That means you select projects D, C, and A, in that order. There is not enough money left for project B, even though its SIR is 1.7.

Table 5-3. Ranking with SIR

Project	Investment	SIR and Rank	
A	$10K	2.0	3
B	10K	1.7	4
C	5K	2.2	2
D	5K	2.3	1

5.2.2 Ranking with NS Method

Look to the right side of Table 5-4 to get a ranking using the NS method. When you select in decreasing order of net savings, projects A and B exhaust your $20,000 budget.

Table 5-4. Ranking with SIR and NS

Project	Investment	SIR and Rank		NS and Rank	
A	$10K	2.0	3	10.0	1
B	10K	1.7	4	6.9	2
C	5K	2.2	2	6.0	4
D	5K	2.3	1	6.5	3

5.2.3 Economic Loss From Using the Wrong Method

Now look in Table 5-5 at how your project selection would be affected and what you would lose if you chose the inappropriate NS method over the appropriate SIR method.

Table 5-5. Comparison ranking

Projects Selected with Each Method		Net Savings Using Each Method	
(1) SIR	(2) NS	(3) SIR	(4) NS
A	A	$10K	$10K
	B		6.9
C			
		6.0	
D			
		6.5	
	Total Net Savings	$22.5K	$16.9K

First look at the rankings with the SIR method. If, in column 3, you add up the individual net savings from projects A, C, and D, that we chose using the SIR, you earn $22,500 in total net savings.

Now look at the ranking with the NS method. If, in column 4, you add up the individual net savings from projects A and B, that you chose using the NS method, you earn only $16,900 in total net savings. In other words, you *lose* the $5,600 difference by using the inappropriate NS method for ranking projects.

6. Exercises

6.1 Exercise in Classifying the Type of Decision and Choosing the Right Method

6.1.1 Background

Suppose that you work for an organization that is responsible for a large portfolio of commercial and residential buildings. Management depends on you to make recommendations, based on economic analysis, regarding building-related investment decisions for both new and existing buildings. Specifically, your responsibilities are to choose the appropriate economic method for evaluating project alternatives, perform or contract out the economic analysis, and, based on findings, make investment recommendations to management.

6.1.2 Exercise

Examine each of the building-related investment decisions listed in the left-hand column in Exhibit 6-1. Identify the types of decisions from the following list and write them in the "Type of Decision" column of Exhibit 6-1.

Accept/Reject
Efficiency Level or Size
System or Design
Priority or Ranking

Then choose the appropriate method(s) from the following list and write its abbreviation in the "Method" column.

Life-Cycle Cost (LCC)
Net Savings (NS)
Savings-to-Investment Ratio (SIR)
Adjusted Internal Rate of Return (AIRR)
Discounted Payback (DPB)

The blanks for the first decision have been filled in as an example.

Hint: If you have difficulty with the classification of investment decisions, review section 2 and Exhibit 2-7. If you are unsure of the appropriate method, review section 4 and Exhibit 4-1.

Building Investment Decision	Type of Decision	Method
1. What is the economically efficient R value of insulation in the walls and above the ceiling of a house?	Efficiency Level	LCC, NS
2. Which orientation of a building is most cost effective?		
3. Is a solar hot water system cost effective?		
4. What kind of insulation—cellulose, fiberglass, or rigid foam—is most cost effective?		
5. What furnace efficiency—AFUE 60%, 75%, or 90%—is most cost effective?		
6. Is a new control system cost effective for managing HVAC equipment?		
7. Which independent investments in a given building—new water heater, new floor tile, or new lighting system—should you buy when each is justifiable on economic grounds, but insufficient funds are available to pay for all of them?		
8. What air conditioner efficiency—SEER 7.0, 9.0, or 11.0—is most cost effective?		
9. Is masonry, wood, or a frame curtain wall the most cost effective?		
10. How many square feet of collector area should you install in a solar energy system?		
11. Is a water heater insulation kit worth buying?		
12. Is single, double, or triple glazing most cost effective?		
13. What heat pump efficiency—HSPF 1.75, 2.0, or 2.25—is most cost effective?		

Exhibit 6-1. Type of decision and choice of method (to be filled in by reader).

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6.1.3 Solution

Your filled in worksheet on types of decisions and choice of methods should look similar to Exhibit 6-2. If you listed the DPB, keep in mind that it has limitations as described in section 3.5.

Building Investment Decision	Type of Decision	Method
1. What is the economically efficient R value of insulation in the walls and above the ceiling of a house?	Efficiency Level	LCC, NS
2. Which orientation of a building is most cost effective?	Design	LCC, NS
3. Is a solar hot water system cost effective?	Accept/Reject	LCC, NS, SIR, AIRR, DPB
4. What kind of insulation—cellulose, fiberglass, or rigid foam—is most cost effective?	Design[a]	LCC, NS
5. What furnace efficiency—AFUE 60%,75%, or 90%—is most cost effective?	Efficiency Level	LCC, NS
6. Is a new control system cost effective for managing HVAC equipment?	Accept/Reject	LCC, NS, SIR, AIRR, DPB
7. Which independent investments in a given building—new water heater, new floor tile, or new lighting system—should you buy when each is justifiable on economic grounds, but insufficient funds are available to pay for all of them?	Priority or Ranking	SIR, AIRR
8. What air conditioner efficiency—SEER 7.0, 9.0, or 11.0—is most cost effective?	Efficiency Level	LCC, NS
9. Is masonry, wood, or a frame curtain wall the most cost effective?	Design	LCC, NS
10. How many square feet of collector area should you install in a solar energy system?	Size	LCC, NS
11. Is a water heater insulation kit worth buying?	Accept/Reject	LCC, NS, SIR, AIRR, DPB
12. Is single, double, or triple glazing most cost effective?	Design[a]	LCC, NS
13. What heat pump efficiency—HSPF 1.75, 2.0, or 2.25—is most cost effective?	Efficiency Level	LCC, NS

Exhibit 6-2. Type of decision and choice of method.

[a]Note that some analysts might classify these types of decisions differently. For example, the kind of insulation might also be classified as a "system" decision. And the choice of glazing might also be classified as an "efficiency level" or "size" decision. It makes no difference which type you choose in this family of types, however, because each family is appropriately treated with the LCC or NS method.

6.2 Exercises in Interpreting Economic Measures

6.2.1 Background

Suppose that you are the manager in your organization who makes decisions about energy conservation in buildings. You are in charge of multiple facilities at several sites. Analysts perform or contract out economic studies of proposed projects, and then submit to you their recommendations. Your responsibility is to evaluate the recommendations and decide on the best investments.

6.2.2 Exercises

Examine each of the following three investment recommendations that have come to your office. Write responses to the recommendations stating whether or not you approve them and your reasons why. Be aware that not all of the economic measures presented will be appropriate, and not all of the recommendations will be cost effective. Also, point out any additional information that you feel you need to know before making a final decision.

6.2.2.1 Efficient Level of Pipe Insulation

Suppose that you have a large number of bare hot water pipes in one of your buildings and you are considering insulating those pipes. You ask one of your cost engineers to come up with some figures and a recommendation. He presents you with Table 6-1 and a recommendation, based on the SIR,

Table 6-1. Economic measures of pipe insulation

Level of Investment	LCC	NS	SIR
Base Case (R-0)	$65,000	NA	NA
R-3	10,500	$54,500	12.4
R-6	9,400	55,600	8.2
R-9	11,000	54,000	6.4

to invest in the first increment of insulation, R-3. What is your decision? Why?

6.2.2.2 Pipe Insulation Solution

Look at LCC and NS. They are the appropriate methods for determining the economically efficient level of insulation. They point to R-6 instead of R-3 for achieving the maximum net savings. Point out to your analyst that the SIR, when measured for each level of insulation in comparison to the base case, is not appropriate for determining the efficient level.[13] You can expect the SIR to drop as insulation increases because energy savings diminish at the margin. Yet it is still appropriate to add the second R-3 increment of insulation for a total R value of 6 because the incremental installment of insulation increases net savings. Or, looking at it another way, the LCC for combinations of energy and insulation required to achieve a target temperature of hot water are minimized at R-6. While the R-9 level of insulation generates positive net savings, they are less than what you achieve with less insulation. Thus investing in R-9 for the pipe would be an "overinvestment" in insulation since you would spend more than you would save in present value terms for that marginal R-3 investment.

[13]Incremental SIRs, as measured between investment increments, are appropriate in choosing efficient levels of investment, but they are not recommended here due to their complexity.

6.2.2.3 Accept or Reject Water-Saving Devices

As energy conservation director of your company's facilities, your responsibilities have been expanded to include water conservation as well as energy conservation. You ask one of your building managers to investigate the economics of water conservation in his building as a test case before looking at the rest of your facilities. The building has showers and faucets. The investment you want to evaluate is installing flow restricting showerheads and faucet aerators on all fixtures. You need to know the present value savings from reduced water consumption and from reduced energy costs (since less steam will be required to heat the water), as well as the present value costs of fixture alterations. Your building manager presents you with the following economic measures of project merit.

NS	=	$900
SIR	=	3.57
DPB	=	4 years

He points out that the project is cost effective in that positive net savings and an SIR greater than 1.0 result from the project's water and steam conservation. He suggests that the project is not worth doing, however, because it takes too long to pay for itself—that is, discounted payback is 4 years (which is less than the study period). He feels that you should only do projects with paybacks less than 3 years. What is your decision? Why?

6.2.2.4 Solution to Water-Saving Devices Decision

Tell him to install the water-saving devices, and have your other building managers evaluate their facilities for similar possible savings. As long as NS are positive and the SIR is greater than 1.0, the project is economically worth doing. Try not to succumb to the payback tune that shortest is best. Assigning an arbitrary payback of, say, 3 years has no economic validity unless you know, for example, that you will dispose of this building in 3 years or less and do not expect your extra conservation expenses to be recouped in the sales price of the building.

6.2.2.5 Multiple Project Selection

Suppose one of your analysts presents to you a recommended set of energy conservation investments. She provides Table 6-2 to support her recommendations. It shows net savings and the savings-to-

Table 6-2. Energy conservation investments and economic measures

Project	Investment Costs	NS	SIR
Attic Insulation	$6,250	$5,000	1.8
Storm Windows	10,833	6,500	1.6
New Conventional Heating System	60,000	12,000	1.2
Time Clock (control equipment	909	1,000	2.1
Solar Heating	16,666	-5,000	0.7

investment ratio for each alternative that her team considered. On the basis of positive net savings, she urges you to accept all of the projects except the solar heating system, whose net savings is negative. What is your decision? Why?

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6.2.2.6 Multiple Project Solution

You can agree with your analyst that the solar system is not cost effective (assuming the computations were done correctly), because the NS and SIR measures indicate that the system in present value terms costs more than it saves over the project's study period. On the other hand, you need more information before you can decide to accept all or any combination of the other projects. Each appears cost effective because it has a positive NS and an SIR greater than 1.0. But ask the analyst if each of these projects is in a different building and is therefore totally *independent* of every other project. If they are independent, then you have a priority and ranking problem. Choose them in descending order of the SIRs until your budget is exhausted. For example, if you have an $80,000 budget, choose all of them. If you have only, say, $8,000, then select the time clock and attic insulation. If the projects are *interdependent*, as they would be if they were in the same building, you will not have enough information in Table 6-2 to make project selections. Adding or deleting any one project affects the others, and these interrelationships must be taken into account to arrive at the economically efficient solution.

Acknowledgments

Thanks are due Stephen Petersen, Linde Fuller, Greg Norris, and Jeanne Powell for their helpful comments, and to Ron Meininger for his guidance and assistance in preparing the video that this workbook supports.

The author acknowledges Mark Ginsberg, Director of the Federal Energy Management Program, and K. Dean DeVine, Program Manager, for their support of the video series.

Appendix A: Glossary of Key Terms

The glossary presents definitions of technical terms used in the video and workbook. Refer to the glossary as needed while viewing the video and reading the workbook.

Adjusted Internal Rate of Return—The annual percentage yield from a project over the study period, taking into account the return from reinvested receipts from the initial project.

Annual Value—The time-equivalent value of past, present, or future cash flows stated as an annually recurring uniform amount over the study period.

Benefit-to-Cost Ratio—The ratio of benefits to costs, where both are discounted to present or annual values. The BCR method is used to measure project worth.

Cost Effective—The condition whereby the present value benefits (savings) of an investment alternative exceeds its present value costs.

Discounting—A procedure for converting a cash flow that occurs over time to an equivalent value at a common time.

Discount Rate—The minimum acceptable rate of return used in converting benefits and costs occurring at different times to their equivalent values at a common time. Discount rates reflect the investor's time value of money (or opportunity cost). Real discount rates reflect time value apart from changes in the purchasing power of the dollar (i.e., inflation or deflation) and are used to discount constant dollar cash flows. Nominal or market discount rates include changes in the purchasing power of the dollar and are used to discount current dollar cash flows.

Economic Evaluation Methods—Various ways in which project benefits and costs can be combined and presented to describe measures of project worth. Examples are life-cycle costs (LCC); net benefits (NB) or net savings (NS); benefit-to-cost ratio (BCR) or savings-to-investment ratio (SIR); and adjusted internal rate of return (AIRR).

Internal Rate of Return—The compound rate of interest that, when used to discount a project's cash flows, will equate costs and benefits.

Investment Costs—The costs associated with acquiring an asset, including such items as design, engineering, purchase, and installation.

Life-Cycle Cost (LCC)—The sum of all discounted costs of acquiring, owning, operating and maintaining, and disposing a building over the study period. Comparing life-cycle costs among mutually exclusive projects of equal performance is one way of determining relative cost effectiveness.

Appendix A: Glossary of Key Terms (continued)

Measures of Project Worth—Economic methods which combine project benefits (savings) and costs in various ways to evaluate the economic value of a project. Examples are life-cycle costs: net benefits or net savings; benefit-to-cost ratio or savings-to-investment ratio; and adjusted internal rate of return.

Mutually Exclusive—A condition where the acceptance of one alternative precludes acceptance of others.

Net Benefits (Savings)—The difference between benefits (savings) and costs, where both are discounted to present or annual values. The net savings (benefits) method is used to measure project worth.

Non-Mutually Exclusive Project—A project whose acceptance does not preclude acceptance of others.

Payback Period—The time it takes for an investment's cumulative benefits or savings from a project to pay back the investment and other accrued costs.

Present Value—The time-equivalent value at a specified base time (the present) of past, present, and future cash flows.

Savings-to-Investment Ratio (SIR)—The ratio of present value savings to present value investment costs. Also computed as the ratio of annual value savings to annual value investment costs. The SIR method is used to measure project worth.

Study Period—The length of time over which an investment is evaluated.

Time Value of Money—The time-dependent value of money arising both from the real earning potential of an investment over time and from changes in the purchasing power of money.

Uncertainty—Uncertainty (or certainty) as used in this report refers to a state of knowledge about the variable inputs to an economic analysis. If the analyst is unsure of input values, there is uncertainty. If the analyst is sure, there is certainty.

Appendix B: Instructor Profiles

HAROLD E. MARSHALL
Dr. Marshall heads the Office of Applied Economics at the National Institute of Standards and Technology. His specialty is developing standard economic methods and risk analysis techniques for evaluating investment projects. He was featured as a subject matter expert in two earlier videos in the series, "Introduction to Life-Cycle Costing," and "Uncertainty and Risk," as well as in the Methods video this workbook supports. He also produced and wrote the "Uncertainty" and "Methods" videos. Dr. Marshall is co-author of the recent book *Building Economics: Theory and Practice*, and has published over 40 articles, chapters in books, and technical papers. He chairs for the American Society for Testing and Materials The Building Economics Subcommittee which has produced nine standard economic methods used worldwide for evaluating investments in buildings and construction. Dr. Marshall also leads the task group on economic methods in the Building Economics Working Commission (W.55) of the International Council for Building Research Studies and Documentation (CIB). His post as advisory editor to the international journal *Construction Management and Economics* helps keep him abreast of developments abroad in building economics. A graduate of The George Washington University (Ph.D. in 1969, M.A., 1965, and B.A., 1964), Dr. Marshall's early career included teaching economics for two years on World Campus Afloat's around-the-world shipboard college and performing economic research at the Department of Agriculture. In recognition of his contributions in building economics, Dr. Marshall received in 1978 the Department of Commerce's Silver Medal Award, in 1986 the American Association of Cost Engineers' highest honor, the Award of Merit, and in 1988 the American Society for Testing and Materials' Award of Merit and accompanying honorary title of Fellow of the Society.

ROSALIE T. RUEGG
Ms. Ruegg, Director of the Economic Assessment Office of the Advanced Technology Program (ATP) of the National Institute of Standards and Technology (NIST), directs economic and business analysis activities for the ATP. The ATP—a $400 million plus program in 1995—promotes U.S. economic growth and competitiveness of U.S. industry by accelerating the development and commercialization of promising, high-risk technologies with substantial potential for large economic benefits. Formerly, she was with the Office of Applied Economics of NIST, where she specialized in developing and applying methods of economic analysis to investment decisions of public and private organizations. She is co-author of a recent book, *Building Economics: Theory and Practice*, published by Chapman and Hall, and the author of more than 50 book chapters, journal articles, and reports. In addition to research, she has developed prototype training curricula in building economics and taught short courses in the U.S. and abroad for university schools of engineering and architecture, government agencies, and professional societies. Ms. Ruegg was earlier a financial economist at the Board of Governors of the Federal Reserve System, and a college instructor in economics. She holds a BA in economics from the University of North Carolina, where she was elected to Phi Beta Kappa; an MA in economics from the University of Maryland, where she was a Woodrow Wilson Fellow; an MBA with a specialty in finance from the American University; and certification as a training specialist from Georgetown University. She received the Department of Commerce's Silver Medal Award for pioneering work in solar economics and, twice, the Center for Building Technology's Outstanding Communicator Award. She developed an earlier video in the series, "Introduction to Life-Cycle Costing."

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Appendix D: Order Information

To receive a listing of LCC workshops or to order single copies of the NIST publications cited in the workbook, please write, FAX, call, or E-mail:

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